Dunkard Creek:
Management Planning Dialogue

Convened by CONSOL
and the West Virginia Department of Environmental Protection

Final Meeting Summary

West Virginia Department of Environmental Protection
601 57th Street South East, Charleston, WV 25304
Coopers Rock Training Room

Attendees

Adam Saslow	Ken Ellison	Scott Rasmussen
Curt Gervich	Loraine Fries	Lou Reynolds
Frank Jernejcic	Dr. Dave Hambright	Dr. John Rodgers
Dr. Mindy Armstead	Ben Lowman	Rick Spear
Beth Burdette	Scott Mandirola	John Wirts
Pat Campbell	Jonathan Pachter	

Goals for This Meeting

At the end of the first day, participants will have:

- Developed a collaborative culture for dialogue
- Firmly agreed upon a framework for memorializing desired outcomes
- Identified key questions for discussion and investigation
- Defined the variants that should be considered for preventing future algal blooms

November 30, 2009

Introductions and Orientation to the Dialogue

In his opening remarks, Cabinet Secretary Randy Huffman welcomed participants from Consol Energy and the West Virginia Department of Environmental Protection (WV DEP) and described his intentions and objectives for holding this two day discussion. Secretary Huffman provided a brief timeline of events related to the fish kill on Dunkard Creek. The secretary suggested that the purpose of the discussions that would occur among Consol and WV DEP was to better understand the science associated with *P. parvum* and to develop a strategy for managing Dunkard Creek and thereby try to prevent another fish kill.

Secretary Huffman and other participants agreed that the discussions at hand were not convened to assign blame for the Dunkard Creek fish kill, to set policy or to develop an overarching watershed management plan for Dunkard Creek. The neutral facilitation team would limit discussion to topics that would enhance the group's understanding of the science related to *P. parvum* and preventing future fish kills from occurring.

Mr. Adam Saslow, Vice President of Sustainability Programs at Plexus Logistics International, introduced several administrative topics and rules for discussion, such as the code of conduct. One participant asked if a new participant from US EPA's regional office could attend the meetings and the group declined. At Mr. Saslow's request participants discussed whether the document produced at the end of the two day dialogue should be publically available and if the document should include participants' names or maintain anonymity. For now, the group opted to allow the document to be circulated among a small number of administrators and staff members at Consol and various government agencies, and that group members' names should not be included in the document. Mr. Saslow emphasized that all participants would have the opportunity to revise the report upon a completion of draft version prior to circulation outside of the group.

Recent History and the Current State of Play – Panel Discussion

Mr. Saslow explained the mechanics of the Expert Panel Discussion. Consol and WV DEP were asked to bring in four experts on golden algae. Each of the experts (named below) was asked to craft a 10-15 minute presentation. At the end of that time, the experts would cross-analyze the views of the others. Following that exchange, the other participants would be permitted to question the experts. The four experts were:

- *Dr. Mindy Y. Armstead – Senior Scientist, Potesta &Associates, Incorporated* [1]
- *Loraine T. Fries – Program Director, Texas Wildlife and Parks Department*
- *Dr. K. David Hambright – Associate Professor, University of Oklahoma*
- *Dr. John H Rodgers –Professor, Clemson University*

Each member of the panel presented data and viewpoints concerning the life history and ecology of *P. parvum* as well as a variety of hypotheses about how the species may have come to occur in Dunkard Creek, bloom[2] and produce its ichthyotoxin. Key relationships and discussions occurred around several issues identified by the data that panelists presented. Observations and discussions that had high levels of

[1] Before and after the meeting WV DEP and WV DNR privately objected to the use of the term "expert" here as it related to Dr. Armistead's status. While there is no doubt concerning the scope and breath of her recently acquired knowledge, nor any question about her expertise in this area, DEP noted difference in the nature and extent to which she has worked with golden algae – relative to the other "experts" participating.

[2] All four experts seemed to have their own definition for the term "bloom." Defining "bloom" is an important step.

agreement among panelists or which raised questions about which panelists were unsure are presented below. These discussions concerned the relationships among *P. parvum* and:

- **pH:** panelists agreed that *P. parvum* toxicities seem to increase in areas with a pH above 7.5 and often around 8, although the organism has been known to bloom and become toxic in lower pH conditions. One panelist pointed out that all algal blooms result in elevated pH as the algae removes carbon dioxide (CO_2) from the water during photosynthesis. The removal of CO_2 directly elevates pH. Unfortunately, no data were represented on pH in the water before, during, or after the blooms in order to support any claims that pH was a factor on Dunkard Creek. The panelists did highlight that the discharge waters from CONSOL did have elevated pH. Panelists mentioned that previous attempts to control *P. parvum* populations and toxicity by manipulating pH (in the published, peer-reviewed literature) in natural settings has not met with success.

- **Stream salinity:** panelists agreed that *P. parvum* seems to be more successful in waters with higher chloride concentrations (and more generally with high levels of total dissolved solids (TDS))[3]. Panelists were unsure, however, if the size and toxicity of the *P. parvum* bloom is because high salinities trigger a reaction in the organism or because *P. parvum*'s competitors are unable to out-compete the organism at these salinity levels (leaving *P. parvum* with a competitive edge in high salinity environments) or both working in concert. Nevertheless, evidence exists in the published, peer-reviewed scientific literature that *P. parvum* tends to thrive in systems with elevated salinities. Panelists seemed to agree that the viability of the organism, whether referring to growth or toxicity, trends downward at lower TDS levels but the extent of that trend is unknown. It is important to note that in one presentation, there was discussion regarding the first occurrences of golden algae in the Pecos River. The data suggested no identifiable cause and effect to the aquatic life kills that occurred, including salinity (though increased salinities in the Pecos River have made conditions unsuitable for Asian clams to recolonize after they, too, were killed by golden alga). Another expert example of algae blooms and fish kills that had occurred in low TDS waters.

- **Stream flow and *P. parvum* mobility:** Panel members participated in a lively and contested discussion about the role of stream flow as it affects the mobility and viability of *P. parvum* and its ability to gain a foothold in Dunkard Creek. At issue was the water velocity in Dunkard Creek, and whether or not lower than normal reduced flows might have allowed *P. parvum* to gain a foothold. There was also discussion of the amount of water CONSOL was withdrawing relative to stream flow and whether the intake had resulted in the observed low flow. [4] No consensus was reached.

  Panelist pointed out that this discussion ties into the natural competition concept. *P. parvum* is not well suited for high velocity waters and will not be competitive if adequate flow is restored to the channel. Panelists were unable to come to agreement about whether or not managing for flow rates would have any effect on the magnitude of any future *P. parvum* blooms. There was ample conversation centered on the impacts of channeling and re-contouring the stream channel as though the watershed was a 404 mitigation site. If such a solution were designed, the Creek might better "flush" the algae from the ecosystem. Of course there was concern expressed over the downstream implications. Panelist did not suggest altering stream beyond the naturally stable channel shape, but rather repairing damaged reaches of the stream where velocity is impaired due

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[3] CONSOL requested that discussions of TDS be limited in this forum.

[4] It is important to note that there are plans to remove two dams in Dunkard Creek this year. Removal of the dams will significantly alter geomorphology of the stream.

to anthropogenic influences. It was suggested that the stream be evaluated to determine whether the current channel shape was effectively transporting water and sediment, which is an important function of streams, or whether the channel could be remediated to facilitate this function.

- **Nutrient regimes and nitrogen to phosphorus ratios:** Panelists agreed that nutrients are necessary to support algal blooms, in general, and that levels of nutrients in Dunkard Creek were sufficient to support significant blooms of the golden algae or other species. Panelists agreed that basic data regarding nitrogen and phosphorus are confounding in regards to *P. Parvum* blooms and toxicity levels. One panelist, however, presented compelling data from Lake Texoma regarding the ratio of nitrogen to phosphorus (N:P). At high N:P, *P. Parvum* seems to produce lower amounts of ichthyotoxins. At low level ratios (as in the late summer of 2009 in Dunkard Creek), the production of ichthyotoxin seems to increase.[5]

- **Competitor species:** many of the discussions that occurred among experts and meeting participants centered on the ambiguity of the relationships between *P. parvum* and the aquatic environment, as opposed to the aquatic environment and *P. parvum*'s competitors. In other words, Panelists could not agree whether the pelagic species had natural competition in a lotic environment. Some panelists felt enhancing the competitive edge of other pelagic species may provide favorable results while others indicated enhancing the competitive edge of lotic species may provide more favorable outcomes. Either way, high salinities seems to create the condition whereby *P. parvum* gains the competitive edge.

[5]Dr. Hambright offered the following off-line explanation in response to a query about "what is low/high N:P?"

Most of the environmental study relating to N:P has revolved around eutrophication and cyanobacteria (i.e., blue green algae). Blue green algae have the ability to "fix" N2 gas (dissolved in the water from the atmosphere) and so tend to out compete other algae when N is in short supply and when P is plentiful - that is at low N:P. A seminal paper was published in Science in 1983 showing that lakes with mass N:P of 29:1 or higher tended not to experience blue green blooms; blue greens were more prevalent in lakes with N:P<29. Many papers have been published since showing that 29 is not necessarily the magic number, but it's a fairly good ballpark estimate. There is a bit of a disjunction here ---- 7:1 is the typical ratio in algae, so why is 29:1 considered low? It has to do with rates of supply. There is no atmospheric form of P; only geological. N is the most abundant constituent of air (80%) as well as the most abundant dissolved gas in water, so it is never really in short supply. However, N2 (gas, dissolved or not) is simply not useable. The majority of N and P in water is typically tied up in biota and because algae need N as nitrate or ammonia and P as phosphate, the rates that these molecules are made available from the biota is typically the limiting step. Hence 29:1 is low if N is converted to nitrate or ammonia slower that P is converted to phosphate. This is a very simplistic explanation. Bottom In summation, if N:P in a lake falls below 29, and P is very abundant, we should be on lookout for blue green algae. The standard mechanism / management approach is to reduce P and thereby increase N:P.

Now for golden algae, it's a different story altogether, because P. parvum *can't fix N2, they must rely on nitrate and ammonia production. However, they have incredible abilities to sequester N from the environment (much better than most algae) when nitrate or ammonia are very low. So, again, the strategy would be to reduce P, because as I pointed out several times, no P, no bloom.*

Can we put a number on things? Not sure, but from our lab experiments conducted at very high P, an N:P of 16:1 or lower (molar) so 7:1 or lower by mass, resulted in higher toxicities. The best guess I can make now would be to use the blue green value (29:1) simply as a yardstick for calling a system low or high. A bit of evidence to back this: P. parvum *blooms in TX and OK in lakes that have low N:P and are usually dominated by blue green algae in the summer.*

- **Differences between *P. parvum* blooms and toxin production:** *P. parvum* fish kills have been documented across a variety of *P. parvum* densities, and often at densities much lower (by two orders of magnitude) than the densities observed in Dunkard Creek. Not all blooms are toxic. Toxicity and fish kills do not necessarily require a bloom of magnitude as that seen in Dunkard Creek. Therefore, panelists agreed *P. parvum* blooms did not necessarily mean fish kills were eminent and vice versa. While general conditions for negative outcomes are well known and documented in the primary literature, subtle variations in those general conditions can be important.

The Levers for a Management Plan

Mr. Saslow facilitated an open discussion among experts AND stakeholders designed to identify key variables for controlling algal blooms and the parameters for their optimization. Participants agreed that the ambiguity of the data and diverse perspectives of panelists made talking about management levers at this point problematic. Instead the group opted to continue discussions about science related to P. parvum. There were several directions suggested as part of the discussion. Significant momentum backed the following:

- Further recognition of the group's limited understanding of *P. parvum* and as a result the difficulty inherent in developing an optimal management strategy.
- A philosophical discussion about the role of management and adaptive management in the face of ambiguity;
- Further focus on the "competitor theory" of *P. parvum*, meaning that patterns related to *P. parvum* reproduction and toxin production may be related to the success of *P. parvum* competitor's as well as *P. parvum*'s response to aquatic conditions;
- Attention to the development of methodologies and technologies for controlling salinity in Dunkard Creek;
- Continued tracking of N:P as an indicator of *P. parvum* bloom and toxin production.

One panelist presented a general population model that presented one explanation of the way that *P. parvum* responds to N:P ratios. This model postulated that *P. parvum* populations increase under relatively high nutrient conditions without causing substantial damage to competitor algae or other organisms, but as nutrients become depleted (due to uptake by the growing population), *P. parvum* growth slows. This phase of nutrient insufficiency seems to trigger production of toxins which then cause death among the competitor algae, thereby releasing their nutrients into the water. These newly released nutrients further the continued increase in *P. parvum* growth. Laboratory results of experiments examining toxicity in *P. parvum* under different nutrient conditions and ratios suggest that this population growth pattern and the production of toxins may be exacerbated under conditions of low N:P availability, such as happens when P loads to a system are increased relative to N loads.

From this point of discussion participants attempted to decipher the presence of an indicator that signaled *P. parvum* was nearing initial population peak, and that toxic production was imminent. The group was unable to determine if such an indicator existed although one of the panelists suggested their research was nearing that level of knowledge.

December 1, 2009

The discussion resumed where yesterday's concluded.

The Levers for a Management Plan

That is, with further discussion of science related to *P. parvum* for the general purpose of honing in on potential management levers for preventing further *P. parvum* related fish kills. Mr. Saslow focused the group's discussion on four key areas that seemed to have group support as the most likely candidates for serving as management levers to prevent future *P. parvum* fish kills on Dunkard Creek. These four areas and a summary of the discussion that centered on each are presented below:

- **Salinity and Conductivity:** Several group members presumed this to be a definitive cause of *P. parvum* growth and pointed to evidence that suggests that as salinity and conductivity increase, *P. parvum* blooms become more common in areas where the algae is known to occur. As the group examined data related to this point on Dunkard Creek they came to the conclusion that this relationship often holds true, but not always. Several felt that that *P.parvum* viability in lower TDS situations is not well characterized.

  One scientist made the assertion that *P. parvum* is a saltwater algae. Another countered that it is a euryhaline algae. It was agreed that *P. parvum* is euryhaline but seems to at least have a preference for saltwater. One expert related the possibility of controlling blooms in Lake Texoma if they re-routed the rivers that flowed through the saline geology into the lake. Yet there, the striped bass fishery, which benefits from saline waters, is too valuable to give up the salinity. They seem willing to live with *P. parvum* so that they have better striper fishing. The case of *P. parvum* and penned salmon off the coast of Norway, salmon are lowered into the colder, denser, fresh water during blooms of *P. parvum* to keep them from the toxin.

- **Nutrient management and N:P:** Throughout the ongoing discussion, participants frequently requested additional data and participants all worked hard to make this data available immediately. At several points group members telephoned and emailed colleagues to find and provide data to the group. One person suggested that were enough nutrients in the stream near Pentress and Brave to allow the algae bloom to occur without any other influences. One such instance occurred when group members collaborated to analyze data related to the N:P ratios in Dunkard Creek in the months leading up to the recent fish kill. This effort revealed that in years prior to the fish kill the N:P ration rarely dropped below what panelists considered a "trigger point" for *P. parvum* and when N:P did reach this level it was only for a short time. In the months just prior to the kill however, the N:P ratio dropped below the trigger point and did not rise, lending further support for N:P role in *P. parvum* growth and toxicity. It seems that a major point of contention among the group was the ability to use N:P as a management lever. For many years natural resource management agencies have worked to reduce nutrient levels in streams. The data presented related to *P. parvum* suggests that once total reductions have been maximized, the ability to use nutrient management controls for minimizing the likelihood of a bloom shifts. At that point, there may be the potential to control the toxicity of a bloom by raising the N:P statistic through additional (tertiary?) reductions in P.

Discussion centered on the source of nutrients in general and it seemed that the consensus was that non-point sources dominated. However, after DEP received data from the field office, it became clear that there were indeed numerous treatment plants permitted to discharge in Dunkard Creek. Since the 1970s, many options have become available for tertiary and even further treatment to greatly reduce the amounts of P being discharged from waste water treatment plants.

- **pH:** Participants were in agreement that there does seem to be a correlation between pH and *P. parvum* population. That is, the organism seems to occur in areas with higher pH. Group members also agreed that pH was a relatively easily managed element of water quality, since Consol already manages for pH at their water discharges on Dunkard Creek. CONSOL personnel indicated that while pH control in their outfalls was manageable, that control would have to be done with CO2 addition to avoid increasing in-stream conductivity through the use of a mineral acid. This pH adjustment would have a limited impact on the creek as a whole. Consol advised that managing pH is complicated since it has a 6-9 compliance level and other parameters (e.g., iron, manganese, aluminum) need to be complied with and pH has an influence on these levels. Group members did highlight several difficulties related to lowering pH in Dunkard Creek. Three of these were:

    1. Lowering pH increase the likelihood of iron staining if not otherwise treated;
    2. Lowering pH to the point that it may kill *P. parvum* may also threaten other species and;
    3. Lowering pH may ultimately be a violation of the Clean Water Act.

    One expert noted that algae need CO_2 from the water to combine with water, fueled by sunlight energy, to make carbohydrates. All photosynthetic organism on this planet use CO_2. In aquatic systems, high algal productivity tends to drive pH up as CO_2 is removed from the water faster than it is returned to the water, either through respiration or from atmospheric diffusion. In water, diffusion of gases tends to be a limiting step and this explains in part, why we see relatively strong swings in pH during algal blooms. At night, photosynthesis no longer predominates, respiration does and so much of the CO_2 is returned to the water. A diurnal series of measurements in Dunkard Creek could pinpoint the source of the high daytime pH (since if photosynthetically driven it should return to background levels by dawn each day). At this time, there is no data to assess this hypothesis.

- **Stream Restoration:** Two of the four experts touted the promise of including stream restoration as a means for increasing stream velocity and reducing nutrient loading. Channelization and contouring might be used to take advantage of *P. parvum's* motility shortcomings.[6]

The group began to develop a "Dashboard" of indicators, levers and pros and cons of management. This was clearly a first cut with much work and progress to continue. As this is an incomplete effort, it is contained herein as Appendix I.

Monitoring for the Efficacy of Management Strategies

[6] Expert biologists from the DEP and DNR, based on their experience and training with natural stream restoration projects, strongly objected to the concept that natural stream restoration was a viable concept for addressing the golden algae problem.

The group began to specifically define the timing of monitoring and appropriate protocols. This was clearly a first cut with much work and progress to continue:

Monitoring in Dunkard Creek

Purpose[7]	Indicators	Frequency	Location	Protocol	Low End Parameter	High End Parameter	Actions
Understanding prevention	pH	Weekly	12-15 stations of DC	Hydrolab			
Water Quality Affecting fish populations	Specific Conductance	Field chemistry -- continuous but grabbed weekly	3-4 Locations	Hydrolab			
Water Quality Affecting fish populations	Total Dissolved Solids (TDS -- e.g., Selenium, Magnesium, metals)	Weekly or Bi-weekly	3-4 Locations (as a precursor)	As appropriate			
Water Quality Affecting Algal Blooms	Nutrients (full N and P chemistry)	Bi-weekly	6 locations	Standard Methods			
Water Quality Affecting fish populations	Sulfates	Field chemistry -- continuous but grabbed weekly	3-4 Locations	Hydrolab			
Water Quality Affecting fish populations	Dissolved Oxygen	Field chemistry -- continuous but grabbed weekly	3-4 Locations	Hydrolab			
Water Quality Affecting fish populations	Chlorides	Weekly or Bi-weekly	3-4 Locations	As appropriate			
Context and Recovery	Type and volume of fish populations	June	6 (Mason Dixon, Pentress, Blacksville, Wana, Miracle Run, above Brave, and then 3-4 in PA - Church, Musky Bridge,)	State Protocol			

[7] Note: Green coding is highest priority monitoring, yellow coding is not quite as important and red coding is more of a luxury.

Purpose[7]	Indicators	Frequency	Location	Protocol	Low End Parameter	High End Parameter	Actions
Context and Recovery	Type and volume of fish populations	Tri-annual	6 (Mason Dixon, Pentress, Blacksville, Wana, Miracle Run, above Brave, and then 3-4 in PA - Church, Musky Bridge,)	State Protocol			
Monitor Algal Community	Periphyton	Seasonally	6 locations	RBP			
Understanding and managing	Water flows (flow stage discharge)	Weekly	3 locations	USGS Protocol			
Early warning/understanding	Toxicity - ITU	Weekly (when algal cells present)	12-15 stations of DC	Modified Israeli Protocol (Bio-assay)			
Water Quality Affecting Algal Blooms	Temperature	Field chemistry -- continuous but grabbed weekly	3-4 locations	Hydrolab			
Water Quality Affecting fish populations	Osmotic Pressure	Weekly	8 Stations in PA	Standard Methods (in PA)			
Early warning/understanding: Monitor Algal Community	Cell counts (of entire assemblage)	Weekly or more often	12-15 stations of DC	Texas/Hema-cytometer Protocol (preferably in volumes of two filters or more)			
Water Quality Affecting Invertebrate Benthos	Chlorides (as a surrogate for salinity)	Weekly		Standard Protocols			
Water Quality Affecting Invertebrate Benthos	Benthic Community (Mussels and Other Invertebrates)	Bi-annually	4 Points at the Mouth of Major Tributaries etc…	RBP and TBA (for mussels)			
Early warning/understanding	PP density and	Often and more often	12-15 stations of DC	PCR			
Early warning/understanding	Toxin concentrations	Often and more often	12-15 stations of DC	Analytical Chemistry			

Purpose[7]	Indicators	Frequency	Location	Protocol	Low End Parameter	High End Parameter	Actions
Understanding and managing	Turbidity	Field chemistry - - continuous but grabbed weekly	12-15 stations of DC	Hydrolab			
Understanding and managing	Chlorophyll A	Weekly	12-15 stations of DC	Standard Methods			
Understanding and managing	Metals Suite	Quarterly	12-15 stations of DC	Standard Methods			
Understanding and managing	Organic Suite	Quarterly	12-15 stations of DC	Standard Methods			
Understanding and managing	DOC and POC	Quarterly	12-15 stations of DC	Standard Methods			
Understanding and managing	Hardness and Alkalinity	Quarterly	12-15 stations of DC	Standard Methods			
Understanding and managing	Fluoride	Quarterly	12-15 stations of DC	Standard Methods			
Understanding and managing	BOD	Weekly	12-15 stations of DC	Standard Methods			
Loading dilution	Continuous flow at large outfalls	Continuous	TBD	As per NPDES			
	Pumping rates and discharge flows		Two CONSOL stations				
	GIS: NPS Inventory						
	GIS: Point Source Inventory						
Flow cytometry - can group many of the above							
Hydrolab can collect continuous data along seven criteria							

Next Steps and Action Items

1. Jonathon Pachter will write a brief statement to be reviewed by all participants regarding the purpose of these meetings *not* being to develop policy, but to focus on science related *P. parvum* for purposes of informing policy related to preventing future fish kills on Dunkard Creek. (We may not need this any longer)

2. Lou Reynolds will provide group with nutrient data from Dunkard Creek from 1995-1997.

3. John Wirts will collect and forward to Plexus all recent (October and November) monitoring data. Plexus will distribute when it becomes available.

4. Rick Spear will look into the proposed removal of a dam on Dunkard Creek. Clearly this will impact the chemical and physical characteristics of the creek and potentially mask or confound any monitoring efforts that are placed on the creek. Mr. Spear will follow up with American Rivers – the group that is coordinating the dam removal project.

   Note: It has been confirmed that promised American Rivers has plans to remove the 2 dams in Brave in the Fall of 2010 most likely in October 2010

5. CONSOL will work with Paul Zimekiewicz at West Virginia University to develop a monitoring plan for Dunkard Creek and will circulate to the group for comment when completed (December 11 or so).

6. Rick Spear will provide participants with water chemistry data that corresponds to the biotic index data and list of taxa occurrences that he provided. It appears at:

   ftp://ftp.state.pa.us//pub/dep/FieldOperations/SouthForkTenmileFEB2009.zip

7. Frank Jernejcic will provide a timeline of events just prior to, during and since the fish kill on Dunkard Creek. Also will provide data regarding tissue and blood samples taken from fish on Dunkard Creek during fish counts after the fish kill.

8. The group agreed that a GIS model of the watershed was a high priority, though no one volunteered to take on this effort (Note: Plexus can take this on if necessary).

Respectfully submitted,

Adam R. Saslow
Vice President – Sustainability Programs
Plexus Logistics, International

Appendix I: The Golden Algae Dashboard

THE GOLDEN ALGAE DASHBOARD

Indicators	Levers	Desired Outcome	Pros	Cons
Chloride Management	Reverse Osmosis		Clean discharge water and the possibility of recycling water and having no discharge	Scaling
				Cleaning filters
	Use of local ponds for dilution			Does not address the problem of high salts being discharged – simply dilutes the problem and pushes it downstream
	Augmentation Wells			Same as above for ponds
	Evaporation			Disposal of salt cakes
	Recycling of water		Allows return of normal baseflow of Dunkard Creek	Corrosion of equipment
pH	Lower AMD from 8 or so to 6.0 in low flow times of year.		No evidence it will affect golden algae	Iron Staining
				Uncertainty
				EPA Technology based Effluent Limits for AMD discharges
TDS				

Indicators	Levers	Desired Outcome	Pros	Cons
Nutrients	Buffer zones for Phosphorous.			
	Agricultural BMP's			
	Improved WWT to drop out Phosphorous		Viable and practical solution	Cost to consumer,
	Watershed-wide Wastewater Treatment Systems (POTW?)			
	Wastewater assessment/feasibility study			
Water Quantity Management and Velocity	Storage and timed releases			
	Channel design, re-contouring and re-routing (restoration)			
	Wells			
Natural Competition	Filter feeders			Ecological competition can only be managed through resources and other environmental variables that play a role in competition
	Phytoplankton at lower salinity			
Temperature				